

***New Millennium EO-1 Advanced Land Imager***

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## ABSTRACT

The primary instrument of the first Earth Orbiter satellite (EO-1) under NASA's New Millennium Program will be an Advanced Land Imager (ALI), with multispectral and imaging spectrometer capabilities. The principal motivation for this mission is to flight-validate advanced technologies which are relevant to the next-generation of Mission to Planet Earth science needs. The ALI telescope is a reflective triplet design employing silicon carbide mirrors with a 15° cross-track field of view. There are three imaging technologies in the ALI. The first is a multispectral panchromatic array with 10 spectral bands in the visible and near infrared and short wave infrared. The two additional imaging technologies are the wedge imaging spectrometer and the grating imaging spectrometer that will each provide a continuous range of wavelength selections from 0.4 to 2.5 μm. The paper will present details of the ALI design and performance parameters.

Key words: Imaging spectrometer, multispectral imaging

## INTRODUCTION

The primary instrument of the first Earth Orbiter satellite (EO-1) under the New Millennium Program (NMP) of the National Aeronautics and Space Administration (NASA) is an Advanced Land Imager (ALI), with multispectral and imaging spectrometer capabilities. Overall direction of the EO-1 mission, and acquisition of the spacecraft, is being carried out by the Goddard Space Flight Center (GSFC) of NASA. MIT Lincoln Laboratory is developing the Advanced Land Imager with NMP instrument team members: Hughes SBRS for the focal plane system, SSG Inc. for the optical system, and JPL for grating fabrication. This instrument comprises an optical system, a focal plane system, a calibration system, and the structural, thermal, and electrical components required forming an integrated unit. Lincoln Laboratory is responsible for the design, fabrication, test and development of the instrument, the software and databases for calibration, and for on-orbit performance assessment.

The NMP is an initiative to demonstrate advanced technologies and designs that show promise for dramatically reducing the cost and/or improving the quality of instruments and spacecraft for future space missions. Under this program, missions are intended primarily to validate such technologies and designs in flight, by providing useful science data to the user community. The goal is to make future operational spacecraft "faster, better, and cheaper," through incorporation of the technologies validated in the NMP. The Earth Orbiter missions will flight validate advanced technologies for next generation Mission to Planet Earth (MTPE) science needs.

The (EO-1) ALI will produce images directly comparable to those from the Enhanced Thematic Mapper Plus (ETM+) of Landsat 7. The ALI will also establish data continuity with previous Landsats and demonstrate advanced capability and innovative approaches to future land imaging. The EO-1 satellite will fly "in formation" with the Landsat 7 satellite in a sun-synchronous, 705 km orbit with a 10:01 am descending node. That is, it will be in an orbit which covers the same ground track as Landsat 7, approximately one minute later than that satellite. The objective is to obtain images of the same ground areas at nearly the same time, so that they may be directly compared. Accordingly, the basic field of view, angular resolution, and spectral bands are matched to those of the ETM+. The EO-1 satellite is co-manifested with Argentina's SAC-C (Scientific Applications Satellite) and is scheduled for launch from the Western Test Range on a Delta 7320 in mid 1999.

## INSTRUMENT DESCRIPTION

The ALI comprises an optical subsystem, two focal plane subsystems, a calibration subsystem, and the electronic, mechanical, and thermal subsystems to form a complete instrument. The essential features of the instrument are schematically depicted in Figures 1 and 2.

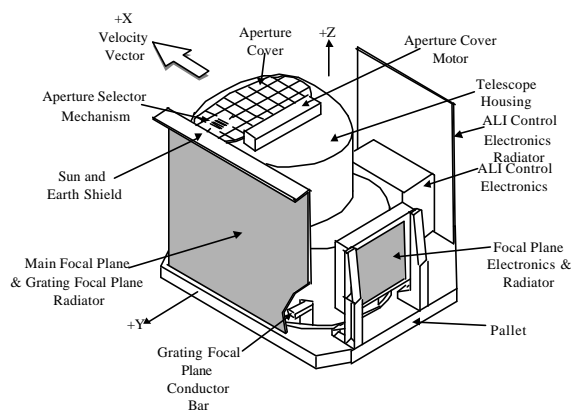


Figure 1. ALI instrument configuration showing the main thermal, mechanical, and electronic components. The instrument pallet will be mounted on the nadir deck of the EO-1 spacecraft.

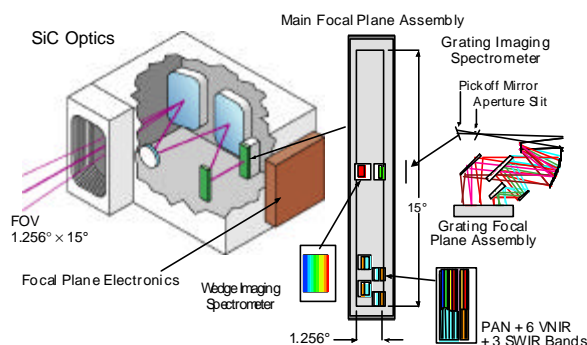
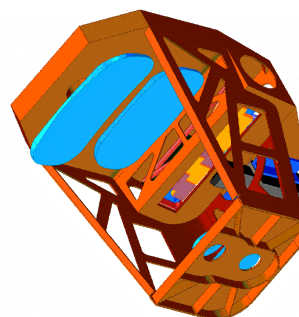


Figure 2. Conceptual layout of the ALI optical system and focal plane detector arrays.

The telescope is a reflective triplet design with a 12.5 centimeter aperture. The design uses four mirrors; the primary is an off-axis asphere, the secondary is an ellipsoid, and the tertiary is a concave sphere; the fourth mirror is a flat folding mirror. Additional optical elements make up the grating imaging spectrometer subsystem.

The design features silicon carbide mirrors and Invar structure with appropriate mounting and attachment fittings. The grating imaging spectrometer will be made of aluminum to limit costs and delivery schedule. A CAD drawing of the silicon carbide mirrors held in place by the Invar metering truss is shown in Figure 3.



#### Telescope features:

- 12.5 cm entrance pupil
- 15° x 1.256° field-of-view
- Telecentric, f/7.5 design
- Unobscured reflective optics
- Silicon carbide mirrors

Figure 3. A design drawing of the silicon carbide mirrors held in place by the Invar metering truss. Key optical parameters are shown in the figure.

Although the optical system supports a 15° by 1.256° FOV, only a small fraction will be populated with detector arrays, as illustrated in Figure 4. The intent is to provide adequate flight validation of the imaging technologies but within the program cost and schedule constraints. There are three imaging technologies in the ALI. The first is a multispectral panchromatic (MS/Pan) array with 10 spectral bands in the visible and near infrared (VNIR) and short wave infrared (SWIR). The pan detectors subtend 10 m square pixels on the ground and are sampled every 10 m as the earth image moves across the array. The MS detectors subtend 30 m and are sampled every 30 m. Four sensor chip assemblies (SCA's) populate a 3° cross-track segment of the focal plane. Each MS band on each SCA contains 320 detectors in the crosstrack direction, while the pan band contains 960 detectors. The total crosstrack coverage from the MS/Pan module is 37 km.

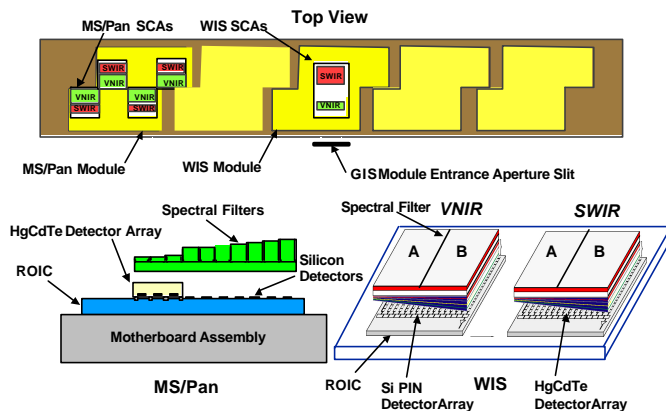


Figure 4. Main focal plane array assembly and illustrations of the NMP imaging technologies.

The two additional imaging technologies are the imaging spectrometer arrays. Two wedge imaging spectrometer (WIS) arrays, one for 0.4 to 1.0  $\mu\text{m}$  wavelengths, and one for 0.9 to 2.5  $\mu\text{m}$ , will be located near the center of the focal plane, and arranged to view a common ground swath. Linear variable wedge filters above the arrays will provide a continuous range of wavelength selections. The spectral rows will be read out and recorded to provide a complete sampling of the spectrum of each ground pixel in the path of the WIS arrays. Grating imaging spectrometer (GIS) arrays with the same wavelength coverage will also view a common ground swath with the WIS. The pixel pitches of the imaging spectrometers in the in-track direction will be commensurate with those of the MS arrays.

The spectral coverages, spectral sampling, and ground sample distances are summarized in Table 1.

### Wide Field of View (15°) All-Reflective Optical System

The optical system will have a 12.5 cm unobscured aperture diameter and a field of view (FOV) 15° in width. It will employ reflecting optics throughout, to cover the fullest possible spectral range. This technology will enable the use of large arrays of detectors at the focal plane, for covering an entire 185 km swath equivalent to Landsat in a “push broom” mode. The optical design features a flat focal plane and telecentric performance, which greatly simplifies the placement of the filter and detector array assemblies.

*Table 1. Summary of the ALI spectral coverage, spectral sampling intervals, and ground sample distances.*

Band	Wavelength ( $\mu\text{m}$ )	Spectral Sampling (nm)	Ground Sample Distance (m)
Pan	0.48 – 0.69	—	10
MS-1'	0.433 – 0.453	—	30
MS-1	0.45 – 0.515	—	30
MS-2	0.525 – 0.605	—	30
MS-3	0.63 – 0.69	—	30
MS-4	0.775 – 0.805	—	30
MS-4'	0.845 – 0.89	—	30
MS-5'	1.2 – 1.3	—	30
MS-5	1.55 – 1.75	—	30
MS-7	2.08 – 2.35	—	30
WIS/VNIR-A (40 bands)	0.41 – 0.66	6.3	30
WIS/VNIR-B (62 bands)	0.59 – 1.00	6.6	30
WIS/SWIR-A (112 bands)	0.93 – 1.54	5.4	30
WIS/SWIR-B (95 bands)	1.52 – 2.50	10.3	30
GIS/VNIR (100 bands)	0.4 – 1.0	6.0	30
GIS/SWIR (133 bands)	0.9 – 2.5	12.0	30

## KEY TECHNOLOGIES

The principal motivation for this mission is to validate advanced technologies, which are relevant to the next-generation of MTPE and Earth Observing System science needs, by demonstration in a space flight mission. Specific technologies to be so validated by the Advanced Land Imager include the following:

### Silicon Carbide Optics

Silicon carbide has many favorable properties for space optical systems. It possesses high stiffness, high thermal conductivity, and low thermal expansion. Although it has been used for space optical elements previously, it has not been used for such large mirrors. Steps will be taken to demonstrate the utility of this promising ceramic for optics in the EO-1 instrument, thus providing the basis for future optical sensors to take advantage of its properties. Although silicon carbide was initially considered for the optics structure, the EO-1 schedule and cost constraints were not consistent with its use.

### Non-Cryogenic Photovoltaic Mercury-Cadmium-Telluride Short Wavelength Infrared Detector Arrays

Photovoltaic SWIR detectors made of mercury-cadmium-telluride (HgCdTe) promise high performance over the 0.9 to 2.5  $\mu\text{m}$  wavelength region at temperatures which can be reached by passive or thermoelectric cooling.

### Hybrid VNIR and SWIR Detectors on a Common Readout Chip

Application of detectors of different materials to a single readout integrated circuit (ROIC) enables a large number of arrays covering a broad spectral range to be placed close together, see Figure 4. This technology is extremely effective when combined with the WFOV optical design being used on the ALI. This is due to the fact that although this optical design provides a large FOV in the cross-track dimension, the FOV in the in-track dimension is much smaller.

### Robust, Accurate In-Flight Calibration

The Advanced Land Imager will demonstrate an innovative approach toward accurate radiometric calibration on orbit, using precisely controlled amounts of the incident solar irradiance. The goals are to achieve 5% absolute and 2% relative radiometric calibration accuracy.

### Imaging Spectrometer Wedge Filter Array Hybrids

The combination of a two-dimensional detector array and a linear-wedge spectral filter is a novel approach to imaging spectrometers, see Figure 4. It offers good relative spectral resolution (of order 100:1) in a light, simple, compact and rugged package. The Advanced Land Imager will include both the VNIR and SWIR arrays, covering the band 0.4 – 2.5  $\mu\text{m}$ , over a 0.78° swath, centered on nadir.

### Imaging Spectrometer Grating Array Hybrid

A grating imaging spectrometer (GIS) with a hybrid array similar to the wedge filter, configured to cover the same band and swath as the wedge filter, will be included to compare the performance of both spectrometers for the same scenes. The GIS and main optical layout is shown in Figure 5.

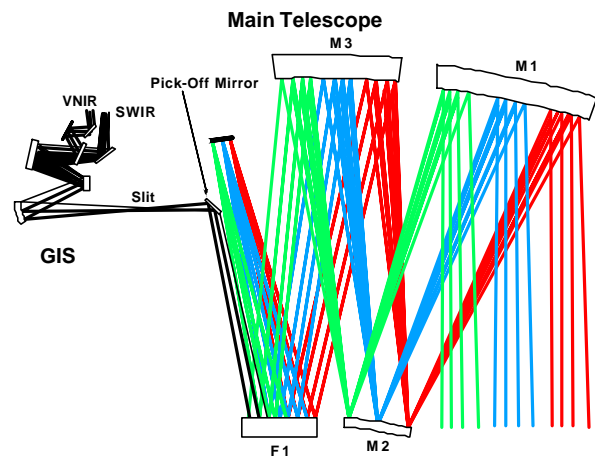


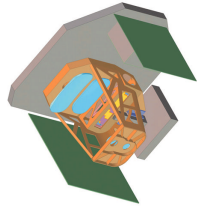
Figure 5. The grating imaging spectrometer (GIS) and main optical system layout

Validation of these advanced technologies will be accomplished primarily through the production of science data, which is directly comparable with that from the Landsat series of satellites. This requires that the Advanced Land Imager include the same multispectral bands (with the exception of the thermal imaging band) at the same ground sampling distances as the Landsats.

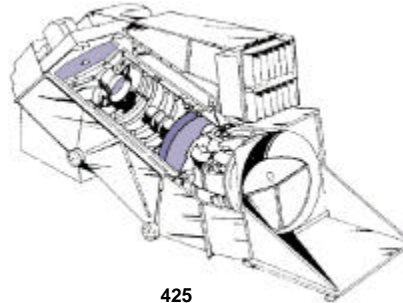
### APPLICATIONS TO OTHER MISSIONS

The technologies which will be flight validated on the EO-1 mission are directed towards next generation Mission to Planet Earth science needs and in particular the applicability for use in an advanced Landsat instrument. An ALI based concept for a future Landsat instrument is illustrated in Figure 6. Here the advanced instrument employs a fully populated MS/Pan focal plane array. A comparison with the ETM+ of some key parameters is shown. Note that for both sensors the ground swath is 185 km. The ETM optical diameter is 41 cm and the 185 km swath is achieved by scanning a turning flat at a 7 Hz rate. The ALI concept uses a 12.5 cm optical diameter and operates in a pushbroom mode (no scan mirror)

**ALI Based Concept for Future  
Landsat Instrument**



**Enhanced Thematic Mapper (ETM)**



100	Mass (kg)	425
100	Power (W)	545
80 × 50 × 50	Size (cm)	196 × 114 × 66
10	VNIR/SWIR Bands	7
6200	Detectors Per Band	16
None	Thermal Bands	1
300	Data Rate (Mbps)	150
10	Pan Resolution (m)	15
4	Relative SNR	1

*Figure 6. An ALI based concept for a future Landsat instrument compared with the ETM.*